Chem 20A Midterm Exam, Winter 2018

Name:

ID:

Please note: your grade will be based on the best 4 questions you answer! you can pick just four questions to answer, or if you answer all five we will grade you based on the best 4 out of these five

Some Physical Constants:

$$h = 6.63 \times 10^{-34}\ \mathrm{J \cdot s} = 4.14 \times 10^{-15}\mathrm{eV \cdot s}$$

$$c(\text{velocity of light}) = 3 \times 10^{8}\frac{\mathrm{m}}{\mathrm{s}}$$

$$1\mathrm{eV} = 1.602 \times 10^{-19}\mathrm{J}$$

$$\mathrm{N_{Avog}}(\text{Avogadro's constant}) = 6.02 \times 10^{23}\mathrm{mol^{-1}}$$

$$m_e(\text{mass of electron}) = 9.1 \times 10^{-31}\ \mathrm{kg}$$

$$R_\infty = 13.6\ \mathrm{eV} = 2.18 \times 10^{-18}\mathrm{J}$$

$$a_0(\text{Bohr radius}) = 0.53\text{Å}$$

$$1\text{Å} = 10^{-10}\mathrm{m}$$

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Question	Points	Maximum
1	~~18~~ 23	25
2	25	25
3	25	25
4	15	25
5	25	25
Best 4 total:		

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for the cellular respiration reaction that breaks down glucose($C_6H_{12}O_6$), how many grams of glucose does the human body consume each minute?

Hint: the balanced equation for respiration reaction is:

$$\underbrace{C_6H_{12}O_6}_{3 mol\ O_2} + \underbrace{6O_2}_{6 mol\ O_2} \Rightarrow 6CO_2 + 6H_2O$$

1.03×10^{-2} mol O_2 $\times \frac{6 \text{ mol } CO_2}{9 \text{ mol } O_2} = .00687$ mol CO_2

let A = # g O_2

A g O_2 $\times \frac{1 \text{ mol } O_2}{31.998 \text{ g } O_2} \times \frac{6 \text{ mol } CO_2}{9 \text{ mol } O_2} = .00687$ mol CO_2

$\frac{6A}{9(31.998)} = .00687$

$6A = 9(31.998)(.00687)$

$A = \frac{9(31.998)(.00687)}{6} = .3297$ g O_2

.3297 g O_2 w/ 9 mol O_2 → 3 mol from $C_6H_{12}O_6$

$C_6H_{12}O_6 : O_2$

3 : 6

1 : 2

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$\frac{.3297}{3} = .1099$ g O_2 in $C_6H_{12}O_6$

%O = $\frac{6(15.999)}{6(12.011)+12(1.008)+6(15.999)} \times 100\% = 53.28\%$

let B = #g of $C_6H_{12}O$

$.5328(B) = .1099$

$B = \frac{.1099}{.5328} = \boxed{.206 \text{ g } C_6H_{12}O_6}$

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b) In the space shuttle, the CO_2 that the crew exhales is removed from the air by a reaction with lithium hydroxide (LiOH) to form lithium carbonate (Li_2CO_3) and water. On average, each astronaut exhales about 20.0 mol of CO_2 daily. What volume of water will be produced when this amount of CO_2 reacts with an excess of LiOH?

Hint: the density of water is about $1.00 \frac{g}{cm^3}$

$$CO_2 + 2LiOH \longrightarrow Li_2CO_3 + H_2O$$

1C 4O | 1C 4O
2Li 2H | 2Li 2H

20 mol CO_2 ⟶ ? cm^3 H_2O

mol → g

$$20 \text{ mol } CO_2 \times \frac{1 \text{ mol } H_2O}{1 \text{ mol } CO_2} = 20 \text{ mol } H_2O$$

$$20 \text{ mol } H_2O \times \frac{18.015 \text{ g } H_2O}{1 \text{ mol } H_2O} = 360.3 \text{ g } H_2O$$

let A = # cm^3 H_2O

$$\frac{360.3 \text{ g } H_2O}{A \text{ cm}^3 \, H_2O} = 1.00 \frac{g}{cm^3} \, H_2O$$

$$A = \boxed{360.3 \text{ cm}^3 \, H_2O}$$

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② Sodium and silver have work functions of 2.46 eV and 4.73 eV, respectively.

a) If the surfaces of both metals are illuminated with a light of wavelength 200 nm,

- Which metal will give off electrons with a higher speed?

$\frac{hc}{\lambda} = KE + W$

$KE = \frac{hc}{\lambda} - W$

$KE = \frac{1}{2}mv^2$ (m constant)

$KE \uparrow, v\uparrow$

$KE_{Na} = \frac{(4.14\times10^{-15}\,eV\cdot s)(3\times10^{8}\,m/s)}{200\times10^{-9}\,m} - 2.46\,eV = 3.75\,eV$

$KE_{Ag} = \frac{(4.14\times10^{-15}\,eV\cdot s)(3\times10^{8}\,m/s)}{200\times10^{-9}\,m} - 4.73\,eV = 1.48\,eV$

$3.75\,eV > 1.48\,eV$

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Sodium will give off e⁻'s with a higher speed

- Calculate the difference between the maximum speeds of the electrons emitted from the two metals.

$KE = \frac{1}{2}mv^2$

$v^2 = \frac{2KE}{m}$

$v = \sqrt{\frac{2KE}{m}}$

$1\,eV = 1.6\times10^{-19}\,J$

$KE_{Na} = (3.75\,eV)(1.6\times10^{-19}\,J) = 6\times10^{-19}\,J$

$v_{Na} = \sqrt{\frac{2(6\times10^{-19}\,J)}{9.109\times10^{-31}\,kg}} = 1.15\times10^{6}\,m/s$

$KE_{Ag} = (1.48\,eV)(1.6\times10^{-19}\,J) = 2.368\times10^{-19}\,J$

$v_{Ag} = \sqrt{\frac{2(2.368\times10^{-19}\,J)}{9.109\times10^{-31}\,kg}} = 7.21\times10^{5}\,m/s$

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$v_{Na} - v_{Ag} = (1.15\times10^{6}\,m/s) - (7.21\times10^{5}\,m/s) = \boxed{4.27\times10^{5}\,m/s}$

b) Calculate the threshold frequency for each material.

$h\nu_0 = W$

$\nu_0 = \frac{W}{h}$

Na

$\nu_0 = \frac{W}{h} = \frac{2.46\,eV}{4.14\times10^{-15}\,eV\cdot s} = \boxed{5.942\times10^{14}\,Hz \text{ for sodium}}$

Ag

$\nu_0 = \frac{W}{h} = \frac{4.73\,eV}{4.14\times10^{-15}\,eV\cdot s} = \boxed{1.143\times10^{15}\,Hz \text{ for silver}}$

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c) Say that sodium is illuminated with light of wavelength 300 nm. Calculate the de Broglie wavelength of the ejected electron.

$\lambda = \frac{h}{p} = \frac{h}{mv}$

$\lambda = \frac{(6.626\times10^{-34}\,J\cdot s)}{(9.109\times10^{-31}\,kg)(7.685\times10^{5}\,m/s)}$

$= \boxed{9.465\,\text{Å}}$

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$\frac{hc}{\lambda} = KE + W$

$\frac{hc}{\lambda} = \frac{1}{2}mv^2 + W$

$\frac{1}{2}mv^2 = \frac{hc}{\lambda} - W$

$W = 2.46\,(1.6\times10^{-19})\,J = 3.936\times10^{-19}\,J$

$v^2 = \frac{2}{m}\left(\frac{hc}{\lambda} - W\right)$

$v = \sqrt{\frac{2}{m}\left(\frac{hc}{\lambda} - W\right)}$

$= \sqrt{\frac{2}{9.109\times10^{-31}\,kg}\left(\frac{(6.626\times10^{-34}\,J\cdot s)(3\times10^{8}\,m/s)}{300\times10^{-9}\,m} - (3.936\times10^{-19}\,J)\right)}$

$= 7.685\times10^{5}\,m/s$

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3.

a) Calculate the number of electrons in the following species:

i) F^-

F: 9 1^- : +1

$9+1 = \boxed{10 \text{ electrons}}$

ii) Ca^{2+}

Ca: 20   2+ : -2

$20-2 = \boxed{18 \text{ electrons}}$

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iii) Fe^{3+}

Fe: 26   3+ : -3

$26-3 = \boxed{23 \text{ electrons}}$

b) Write down the electronic configuration of the following species:

i) Al   13 e⁻'s   3p

$\boxed{1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^1 \text{ or } [Ne]\ 3s^2\ 3p^1}$

$\underbrace{\underbrace{\underbrace{\underbrace{2+2}_{4}+6}_{10}+2}_{12}+1}_{13}$

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ii) Cr   24 e⁻'s   n=4 ; 3d

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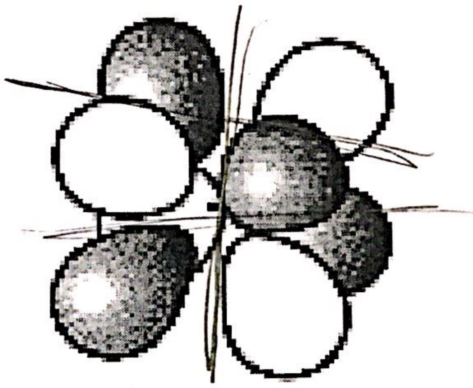
c) How many angular nodes are there in the following orbital? (White denotes positive values and gray negative values)

Given that the orbital has no radial nodes, determine the identity of the orbital.



$\boxed{\text{3 angular nodes}}$

$n = l + 1 + r$

$n = 3 + 1 + 0$

$= 4$

$r = 0$

$l = 3$

$l = 3$

$\to f$

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$\boxed{\text{4f orbital}}$

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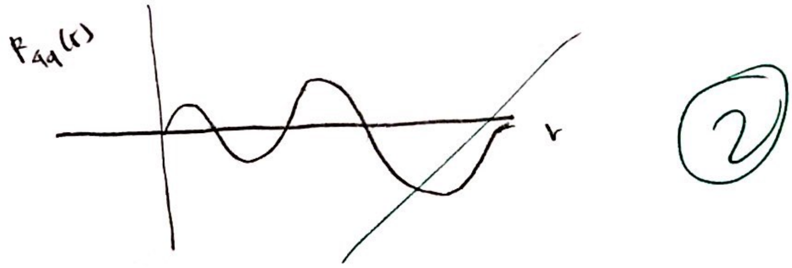
4. The radial part of 4d orbital in hydrogen is

$$R_{4d}(r) = \frac{1}{96\sqrt{5\,a_0^3}}(6-\rho)\rho^2 e^{-\frac{\rho}{2}} \quad (\rho = \frac{r}{2a_0})$$

3 radial nodes

a) Roughly sketch the radial part of the hydrogen 4d orbital.



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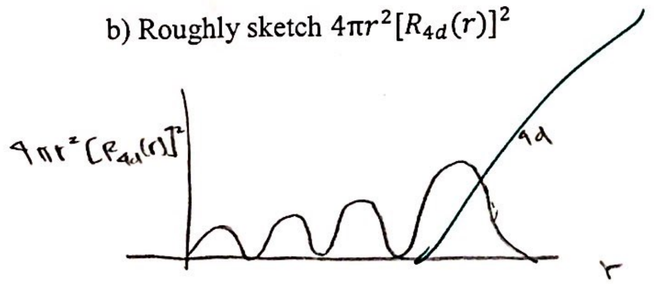
b) Roughly sketch $4\pi r^2[R_{4d}(r)]^2$



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c) Find the radial nodes of the 4d orbital

$R_{4d}(r) = 0$

$$\boxed{\frac{1}{96\sqrt{5a_0^3}}}\left(6-\frac{r}{2a_0}\right)\left(\frac{r}{2a_0}\right)^2 \boxed{e^{-\frac{r}{4a_0}}} = 0 \quad \rightarrow \text{never zero}$$

constant

$$\left(6-\frac{r}{2a_0}\right)\left(\frac{r}{2a_0}\right)^2 = 0$$

$r = 0 \qquad 6 - \frac{r}{2a_0} = 0$

$\frac{r}{2a_0} = 6 \qquad r = 12a_0$

$\boxed{\text{when } r = \cancel{0},\ 12a_0}$

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d) What is the probability of finding the electron at distance between a_0 and $1.0001a_0$ from the nucleus?

$r = a_0$

$dr = 10^{-4}\,m$

$= 1.89\times10^{6}\,a_0$

$|R_{4d}(r)|^2 4\pi r^2 dr$

$a_0 = .529\times10^{-10}\,m$

$$|R_{4d}(r)|^2 = \frac{1}{96^2(5)a_0^3}\left(6-\frac{r}{2a_0}\right)^2\left(\frac{r}{2a_0}\right)^4 e^{-\frac{r}{2a_0}}$$

$$|R_{4d}(r)^2|\,4\pi r^2 dr = \frac{1}{96^2(5)a_0^3}\left(6-\frac{a_0}{2a_0}\right)^2\left(\frac{a_0}{2a_0}\right)^4 e^{-\frac{a_0}{2a_0}}(4\pi)(a_0^2)(1.89\times10^6 a_0)$$

$$= \frac{1}{96^2(5)\cancel{a_0^3}}\left(6-\frac{1}{2}\right)^2\left(\frac{1}{2}\right)^4 e^{-\frac{1}{2}}(4\pi)(\cancel{a_0^2})(1.89\times10^6 \cancel{a_0})$$

$$= \frac{(5.5)^2(.5)^4 e^{-1/2}(4\pi)(1.89\times10^6)}{(96)^2(5)}$$

$$= \boxed{591.691}$$

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5.

a) Suppose that for an ion with only one electron, the transition from an n = 8 state to an n = 4 state will lead to emission of a photon with a wavelength 216 nm. Based on that, determine the identity of the ion.

$n=8 \rightarrow n=4$

$\Delta E = -$

$\lambda = 216 nm$

$\Delta E = E_4 - E_8$

$= -R_\infty \frac{Z^2}{4^2} - \left(-R_\infty \frac{Z^2}{8^2}\right)$

$= Z^2 R_\infty \left(\frac{1}{64} - \frac{1}{16}\right)$

$Z^2 (13.6 eV)\left(\frac{1}{64} - \frac{1}{16}\right) = -E_{phot}$

$-Z^2 (13.6 eV)\left(\frac{3}{64}\right) = -\frac{hc}{\lambda}$

$Z^2 = \frac{(4.14 \times 10^{-15} eV\cdot s)(3 \times 10^8 m/s)}{216 \times 10^{-9} m} \cdot \frac{64}{3} \cdot \frac{1}{13.6 eV}$

$Z = \sqrt{\frac{64(4.14 \times 10^{-15})(3 \times 10^8)}{3(13.6)(216 \times 10^{-9})}} = 3$

$Z = 3 \rightarrow Li$

$\boxed{ion = Li^{2+}}$

b) Suppose we shine light of a certain frequency on a Li^{2+} ion whose electron is in its n=2 energy state, and we observe that the electron absorbs a photon and is ejected from the ion with a kinetic energy of 3.0 eV (i.e., the electron not only moved infinitely away from the nucleus but also got an extra 3.0 eV of kinetic energy). Calculate the frequency of the photon.

$2 \rightarrow n = \infty$

$\Delta E = +$

$KE = 3 eV$

$\nu = ?$

$Z = 3$

$E_{phot} = \Delta E + KE$

$h\nu = (E_\infty - E_2) + KE$

$h\nu = -R_\infty \frac{Z^2}{\infty^2} - \left(-R_\infty \frac{Z^2}{2^2}\right) + KE$

$h\nu = R_\infty Z^2 \left(\frac{1}{4} - \frac{1}{\infty^2}\right) + KE$

$\nu = \frac{R_\infty Z^2 \left(\frac{1}{4}\right) + KE}{h}$

$= \frac{(13.6 eV)(3)^2\left(\frac{1}{4}\right) + 3 eV}{4.14 \times 10^{-15} eV\text{-}s}$

$= \boxed{8.116 \times 10^{15} Hz}$

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